The role of MRI in bone marrow imaging

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MRI has unique capabilities in the visualization of both the normal and abnormal bone marrow. Moreover, MRI allows us to monitor physiological conversion from hematopoietic (red) to fatty (yellow) marrow and to assess variants in the distribution of both marrow types.

In hematopoietic bone marrow, the content of fat is much higher than in the red marrow, in which the signal characteristics are dominated by the higher proportion of water, which is due to the cellular elements. The content of bony trabeculae within the bone marrow is also important for signal characteristics, especially when pulse sequences are applied which are sensitive to susceptibility effects.

In the newborn, all bones contain red marrow. During infancy, childhood and adolescence, conversion of red to yellow marrow takes place. This process of bone marrow conversion proceeds in centripetal direction. Most peripheral bones, such as the phalanges of the hands and feet are involved earlier than the more central elements of the lower leg and forearm, respectively. Within the long bones, the conversion of the bone marrow starts in the diaphyses and progresses to the metaphyses. The epiphyses, on the other hand, contain yellow marrow when they ossify. At the age of about 22 to 25 years of age, the adult distribution of red and yellow is found. Hematopoietic bone marrow in adults is found within vertebral bodies, pelvis, ribs, scapula, skull as well as in the proximal portions of the humerus and femur. It should be noted that fat content increases with age also in those skeletal elements which contain yellow marrow and that islands of hematopoietic marrow may exist in the long bones, especially in the metaphyses which must not be misinterpreted as an infiltration of neoplastic tissue. Moreover, various pathological and physiological conditions which are associated with a need of increased red or white cell production, may result in focal or diffuse reconversion of yellow to red marrow: Increased menstrual blood loss, severe infections, extensive athletic activities (e.g. marathon runners), extensive bone marrow infiltration by neoplasms or leukemia, hemoglobinopathies etc. MRI is able to depict the distribution of yellow and red marrow and to diagnose pathological conditions within the bone marrow. The selection of adequate pulse sequences is critical. T1-weighted spinecho and STIR sequences are most useful for this differentiation. In- and out-of-phase gradient echo sequences as well as T2* weighted gradient echo sequences may add valuable information. In T2-weighted (fast) spin echo sequences and contrast enhanced T1-weighted sequences, on the other hand, the contrast between fatty and hematopoietic marrow is greatly reduced. Initial results indicate that diffusion weighted imaging (DWI) may be superior to other techniques for specific questions, e.g. differentiation of neoplastic and osteoporotic fractures of the vertebrae.

MRI is particularly sensitive for the detection of bone marrow manifestations of lymphoma, multiple myeloma as well as bony metastases. This issue will be addressed in another lecture specifically devoted to this subject. There exist many other disorders of the bone marrow which are readily detected using MRI. Some of them may play an important role in oncologic imaging.

Bone infarcts and aseptic necrosis

Bone infarct and aseptic necroses frequently occur in tumor patients and patients with leukemia treated with cytotoxic drugs and steroids. When pain and restriction of motion is reported by the patients bony metastases are suspected. In the late phase, bone infarcts are displayed as polycyclic areas with a dense rim of calcification in the periphery on plain radiograms which allow for a straightforward diagnosis. In the early stage, however, when bone infarcts cause severe pain, radiographic signs are very discrete. MRI shows high signal intensity on STIR and fat sat CE scans in the periphery of the lesion, normal fat signal in the center and edema in the adjacent normal bone marrow thus allowing for a specific diagnosis.

Aseptic necroses are located in the subchondral region of various joints, such as the femoral and humeral

head, the femoral condyles and the talus. In the early stage, minor degrees of osteopenia or the crescent-sign (semicircular lucency) are the only plain film findings. In MRI the necrotic zone is clearly demarcated and depending upon the composition of the necrotic tissue high, intermediate or low signal intensities are found. The 'double line sign' at the periphery of the necrotic zone is regarded as a specific feature of aseptic necrosis.

Stress and insufficiency fractures

Following radiation therapy, chemotherapy and immobilization patients treated for malignant tumors, who are frequently at older age, are prone to insufficiency fractures. Especially previous radiation therapy results in weakening of the bone. Insufficiency fractures are often located in the femoral neck, sacrum, iliac bones and lower lumber vertebrae. Bone scanning shows focal tracer accumulation in the areas affected by insufficiency fractures thus mimicking bony metastases. With MRI (and CT) these insufficiency fractures are readily diagnosed. Longitudinal bands of low signal intensity with adjacent bone marrow edema are indicative of insufficiency fractures. In CT, bond-like or geographic areas of sclerosis are visualized.

Osteomyelitis and cellulitis

Plain radiography is insensitive for the detection of osteomyelitis before larger areas of trabecular and cortical bone are destroyed (up to 3 weeks after the onset of symptoms). Bone scanning is highly sensitive but non-specific. MRI, especially when using fat sat CE scans allows for early diagnosis and precise assessment of the location and extent of the infectious process. Extension within the bone marrow, involvement of the cortex, and paraosseus involvement are visualized. Following contrast enhancement, abscess cavities and the hypervascular abscess membrane are depicted. Following surgical treatment of bone tumors and skeletal metastases the differentiation of reactive tissue and early infection, however, may be difficult or impossible. SAPHO syndrome is a specific entity which is associated with palmo-plantar pustulosis, psoriasis or skin infections (acne conglobata). It involves multiple skeletal elements, especially the proximal sternum and the medial portions of the clavicles. However, multiple other bones can also be involved. Thickening, irregular structure and multiple small bony destructions are found in the involved bones. These features may be misinterpreted as neoplasms and this diagnosis may be supported by multifocal tracer accumulation in the bone scans. MRI and CT findings also have an aggressive appearance and awareness of this entity is important to avoid false diagnoses.

Chronic recurrent multifocal osteomyelitis (CRMO) is found in children and adolescents and multiple bones are affected by a chronic type of osteomyelitis. Multifocality may also lead to misdiagnosis of osseous metastases.

Leukemia

In acute and chronic types of leukemia, the normal bone marrow is replaced by neoplastic cells. The extent of bone marrow involvement is variable. The radiologist may detect homogeneous marrow abnormalities when MRI is performed due to symptoms unrelated to a systemic bone marrow disorder (e.g. joint pain) and has to insist on a thorough examination by the internist.

For monitoring patients under treatment for leukemia, MRI proved not to be useful, even if some anecdotal reports exist in which relapse of the disease was first diagnosed by MRI. Due to signal alterations within the bone marrow in patients with leukemia, other pathological conditions such as aseptic necroses, osteomyelitis and spondylitis may be difficult to be detected.

Suggested reading

1. Dooms GC, Fisher MR, Hricak H, Richardson M, Crooks LE, Genant HK. Bone marrow imaging: magnetic resonance studies related to age and sex. *Radiology* 1985 May; **155**(2): 429-432.

2. Plecha DM. Imaging of bone marrow disease in the spine. *Semin Musculoskelet Radiol* 2000; **4**(3): 321-327.

3. Richards MA, Webb JA, Jewell SE, Gregory WM, Reznek RH. In-vivo measurement of spin lattice relaxation time (T1) of bone marrow in healthy volunteers: the effects of age and sex. *Br J Radiol* 1988 Jan; **61**(721): 30-33.

4. Siegel MJ, Luker GG. Bone marrow imaging in children. *Magn Reson Imaging Clin N Am* 1996 Nov; **4**(4): 771-796.

5. Smith SR, Williams CE, Davies JM, Edwards RH. Bone marrow disorders: characterization with quantitative MR imaging. *Radiology* 1989 Sep; **172**(3): 805-810.

6. Steiner RM, Mitchell DG, Rao VM, Murphy S, Rifkin MD, Burk DL Jr, Ballas SK, Vinitski S. Magnetic resonance imaging of bone marrow: diagnostic value in diffuse hematologic disorders. *Magn Reson Q* 1990 Jan; **6**(1): 17-34.

7. Takagi S, Tanaka O. The role of magnetic resonance imaging in the diagnosis and monitoring of myelodysplastic syndromes or leukemia. *Leuk Lymphoma* 1996 Nov; **23**(5-6): 443-450.

8. Takagi S, Tsunoda S, Tanaka O. Bone marrow involvement in lymphoma: the importance of marrow magnetic resonance imaging. *Leuk Lymphoma* 1998 May; **29**(5-6): 515-22.

9. Tardivon AA, Vanel D, Munck JN, Bosq J. Magnetic resonance imaging of the bone marrow in lymphomas and leukemias. *Leuk Lymphoma* 1997 Mar; **25**(1-2): 55-68.